eRHIC Detector Magnet Design

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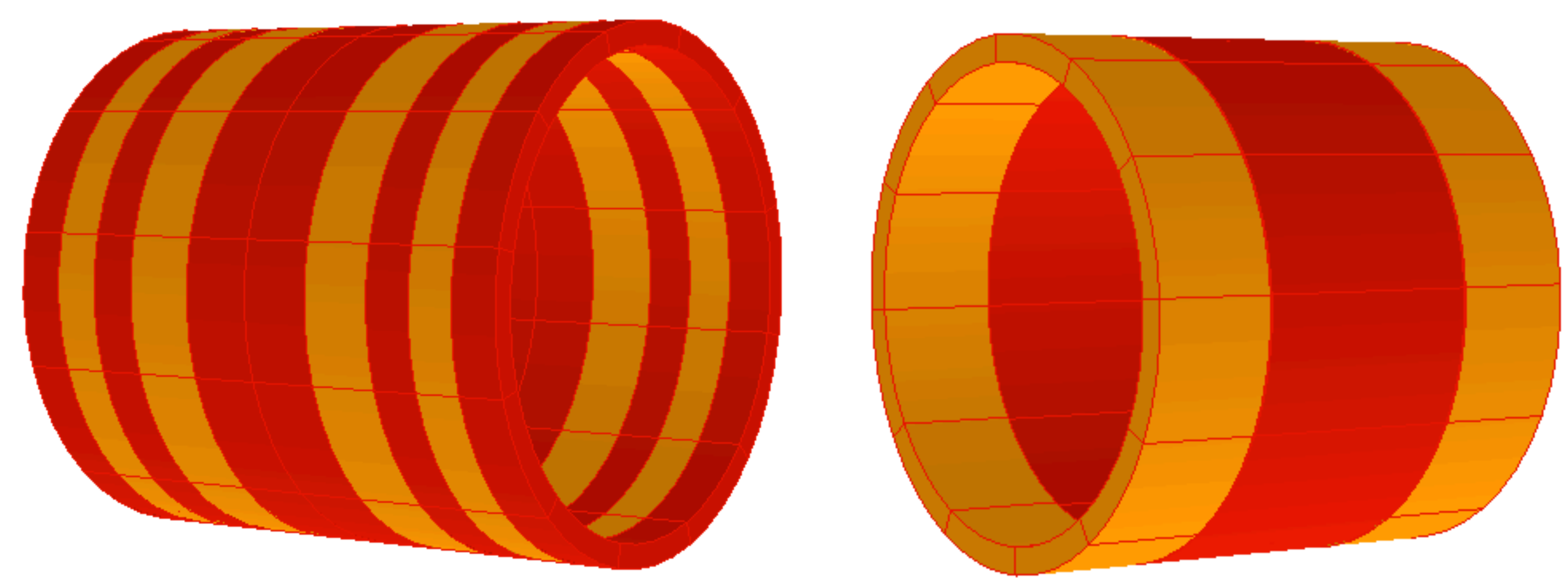
Abstract

The proposal to add an electron beam to the Relativistic Heavy Ion Collider (eRHIC) at Brookhaven National Laboratory (BNL) is part of a worldwide collaboration to realize an Electron-Ion Collider (EIC). The EIC will allow physicists to gain new insight into gluons, the force carriers of the strong interaction.

In any particle detector, super conducting magnets are used to apply large magnetic fields to not only guide beams of particles but to bend the debris of particles resulting from a collision of two beams. The ideal magnet will allow users to measure each particle's momentum with high resolution and provide adequate spacing for the mounting of various particle detectors components (tracking, calorimeters, etc.)

Two major magnet designs that would be the ideal synthesis of functionality and plausibility were created and studied. They are the Multiple Ring Solenoid version B1 (MRS-B1) and the Bifurcated EncLosed LinEar solenoid (BELLE). Further study is necessary to determine which of the two designs is best suited for the eRHIC.



OPERA-3D/2D allows the user full control over the geometry of a magnet model. The program is also used to map out and export magnetic field values for use in other detector simulations. Above, from left to right, are the MRS-B1 and BELLE (without shielding), with **bi-colored** components to show different rings.

Design Considerations

Momentum Resolution

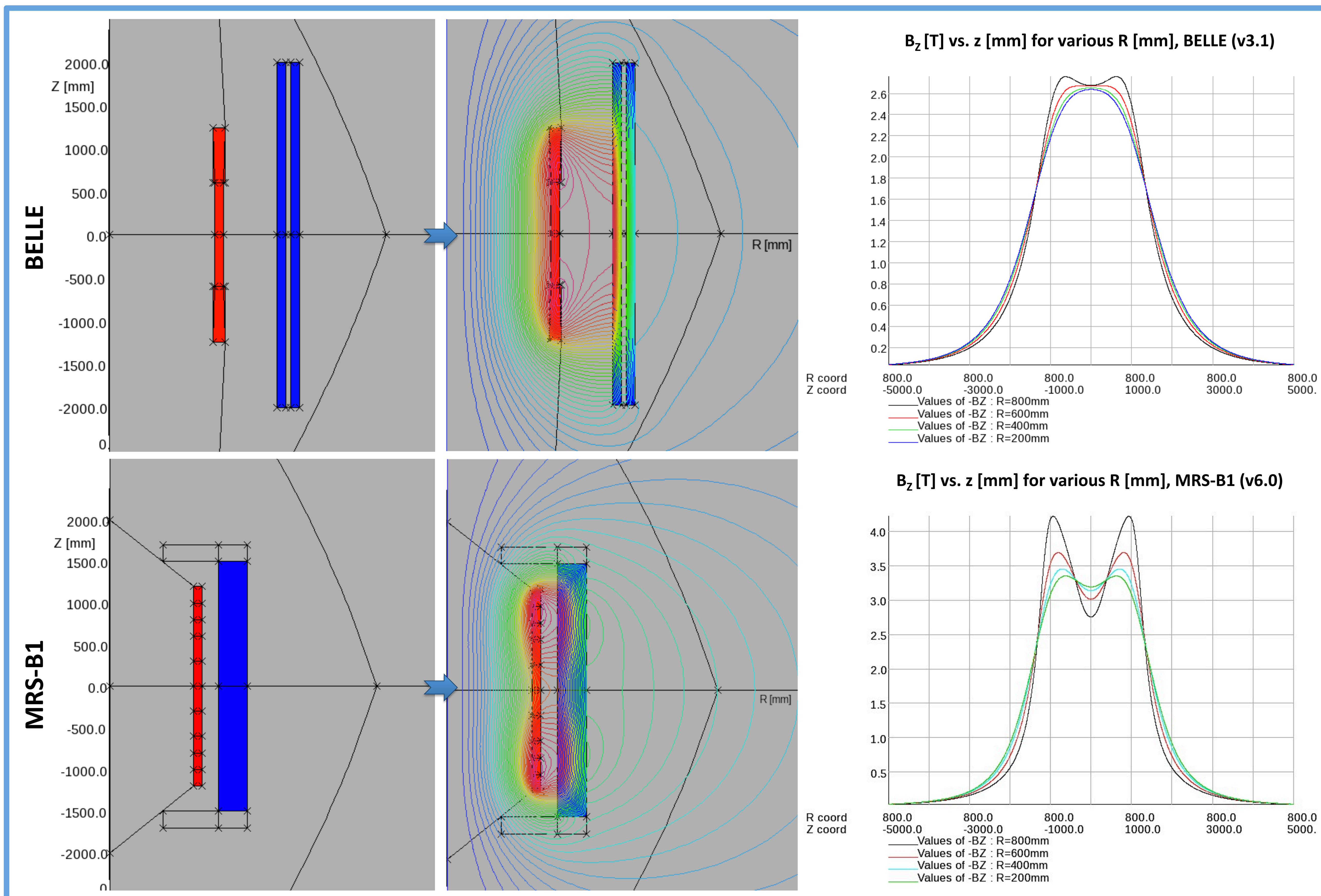
The eRHIC experiment involves an electron hitting either protons or ions. These collisions produce hadrons (e.g., protons, kaons) and leptons (e.g., electrons, positrons). Some particles scatter through a small angle close to the beam axis, which means radial magnetic field components are very important. As the particles pass through the magnetic field, their trajectories begin to spiral around field lines. This spiraling/bending is then used to determine a particle's momentum and mass. In a solenoid, the momentum resolution is approximately given by $\delta p/p \approx p/(BL^2)$, where p is the momentum, B is the magnetic field strength, and L is the particle's radial path length. In order to improve momentum resolution, the BELLE and MRS-B1 aim to balance path length with magnetic field. By keeping a balance between length and field, experimental needs can be preserved while operating and construction costs are minimized. In order to identify hadrons according to their type (π, K, p), Ring Imaging Cherenkov Detectors (RICH) are used. To determine the mass of a hadron, we measure the momentum and the opening angle of the cone Cherenkov light θ_C that is emitted from a particle passing through a material. The particle's mass is then determined by $\cos \theta_C = 1/(n\beta)$, where n is the refractive index of the material, $\beta = v_p/c$, and v_p is the particle velocity. A precise measurement of the momentum is crucial for this concept to work.

Time Projection Chambers

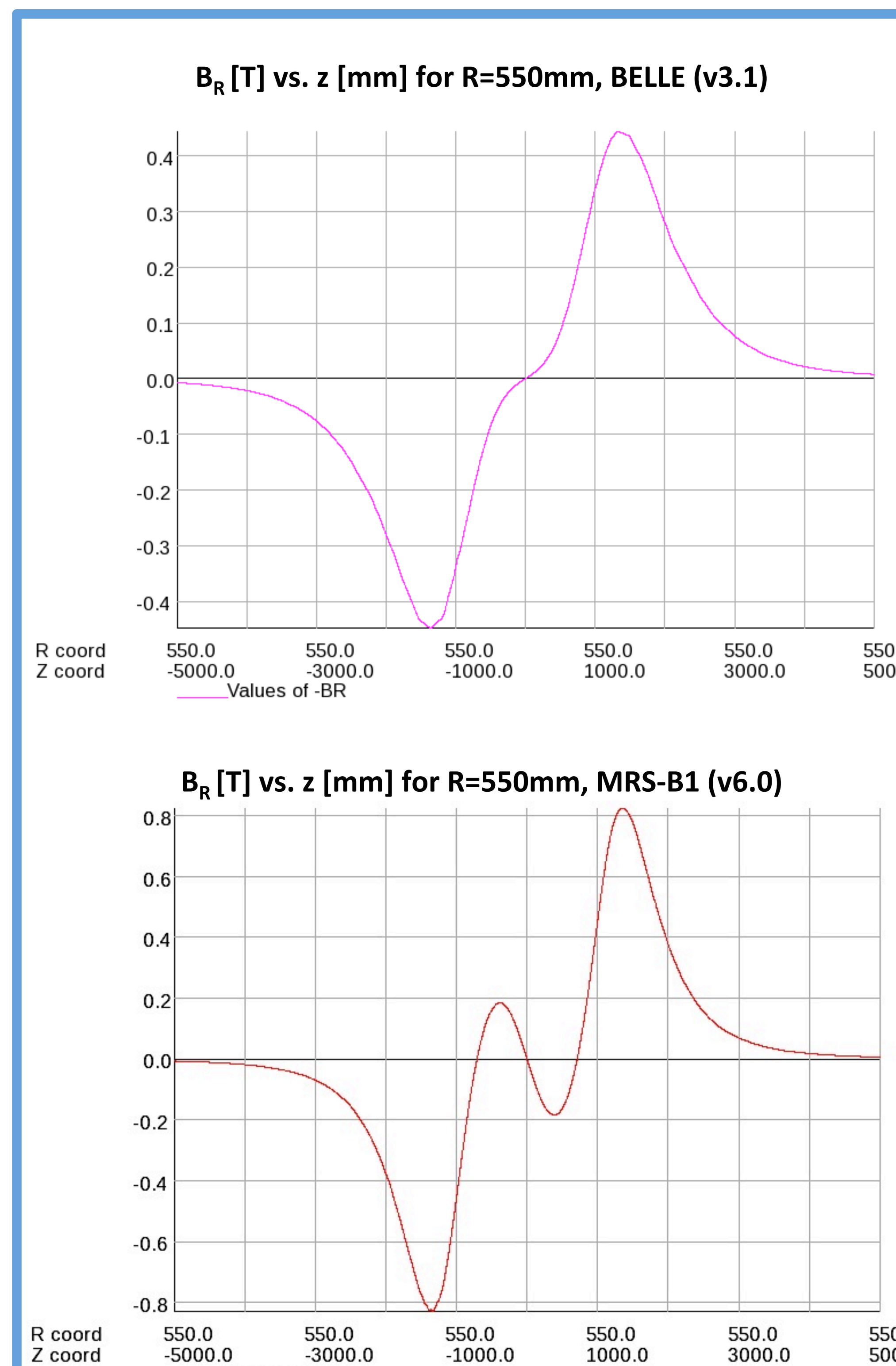
The time projection chamber (TPC) is necessary for differentiating between particle masses and determining particle momentum. The eRHIC TPC is currently slated to have a length of 200 cm and a diameter of 800 cm. The thickness, as determined perpendicular to the beam axis, begins at 30 cm from the beam pipe. The TPC yields particle locations at various times. A helical trajectory is fitted to these locations and then the particle's momentum may be discerned. The TPC's data is utilized best when momentum resolution is as small as possible.

Calorimeters

There are two kinds of calorimeter: an Electromagnetic Calorimeter (ECAL) and a Hadronic Calorimeter (HCAL). An ECAL measures the energy of electrons and photons, while an HCAL measures the energy of hadrons such as pions, protons and neutrons.



Top, left to right: OPERA-2D views of the BELLE, before and after the magnetic field potential mapping, a plot of the z-component (parallel to the beam line) of the magnetic field at various radii from the beam line. Bottom, left to right: OPERA-2D views of the MRS-B1, before and after the magnetic field potential mapping, a plot of the z-component (parallel to the beam line) of the magnetic field at various magnet radii. The more uniform magnetic field in the BELLE enables easier particle track reconstruction from the TPC. The four pictures to the left show the magnet components in **red** and steel yokes in **blue**. In order to lower overall cost, small voids may be left in the yoke to limit steel volume while still maintaining space to return magnetic flux.



In the region of the TPC, particle bending should be maximized to later enable charge identification and increase momentum resolution. At 550 mm (the center of the TPC region), we would want strong radial magnetic field components to be present in order to accomplish this. Above, the MRS-B1 clearly has higher field components, but its efficacy needs to be determined through detector simulations.

References

[1] A. Yamamoto, Nucl. Instr. And Meth. A 453 (2000) 445-454
[2] S. Eidelman *et al.*, Physics Letters **B592**, 1 (2004) 32-40